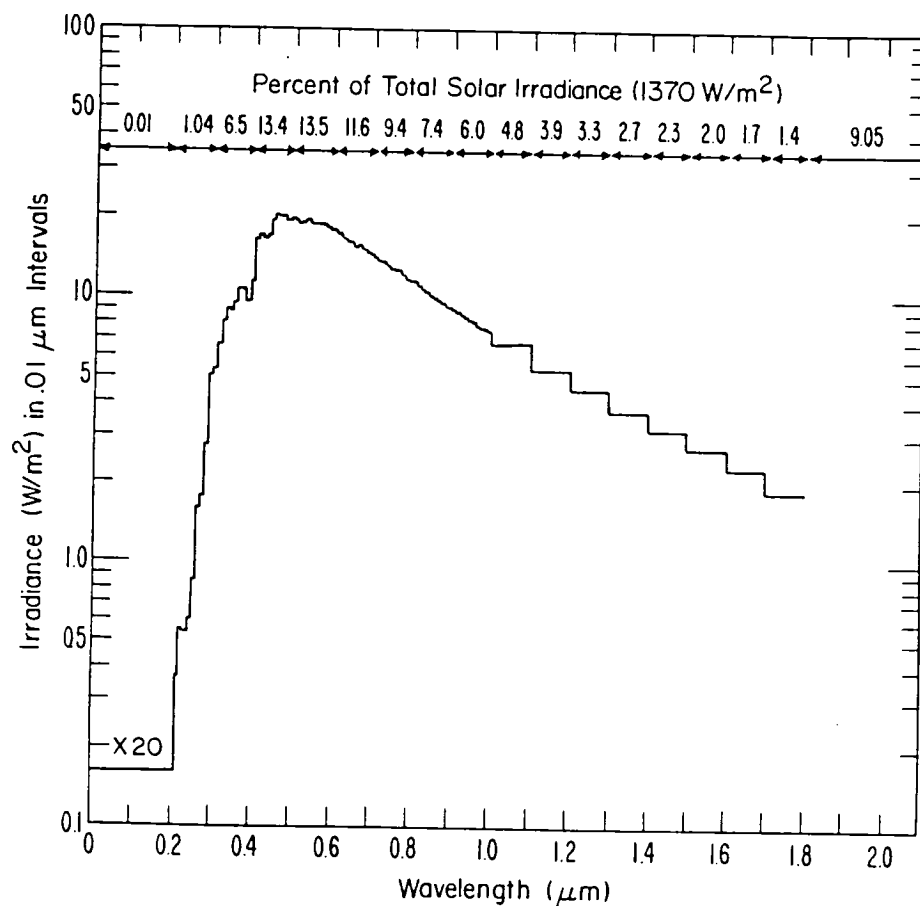# AN ESTIMATE OF CHANGES IN THE SUN'S TOTAL IRRADIANCE CAUSED BY UV IRRADIANCE VARIATIONS FROM 1874 TO 1988

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## ABSTRACT

Enhanced emission from bright solar faculae is a source of significant variation in the sun's total irradiance. Relative to the emission from the quiet sun, facular emission is known to be considerably greater at UV wavelengths than at visible wavelengths. Determining the spectral dependence of facular emission is of interest for the physical insight this may provide to the origin of the sun's irradiance variations. It is also of interest because solar radiation at $\lambda < 300$ nm is almost totally absorbed in the earth's atmosphere. Depending on the magnitude of the UV irradiance variations, changes in the sun's irradiance that penetrates to the earth's surface may not be equivalent to total irradiance variations measured above the earth's atmosphere. Using an empirical model of total irradiance variations which accounts separately for changes caused by bright faculae from those associated with dark sunspots, the contribution of UV irradiance variations to changes in the sun's total irradiance is estimated during solar cycles 12 to 21.
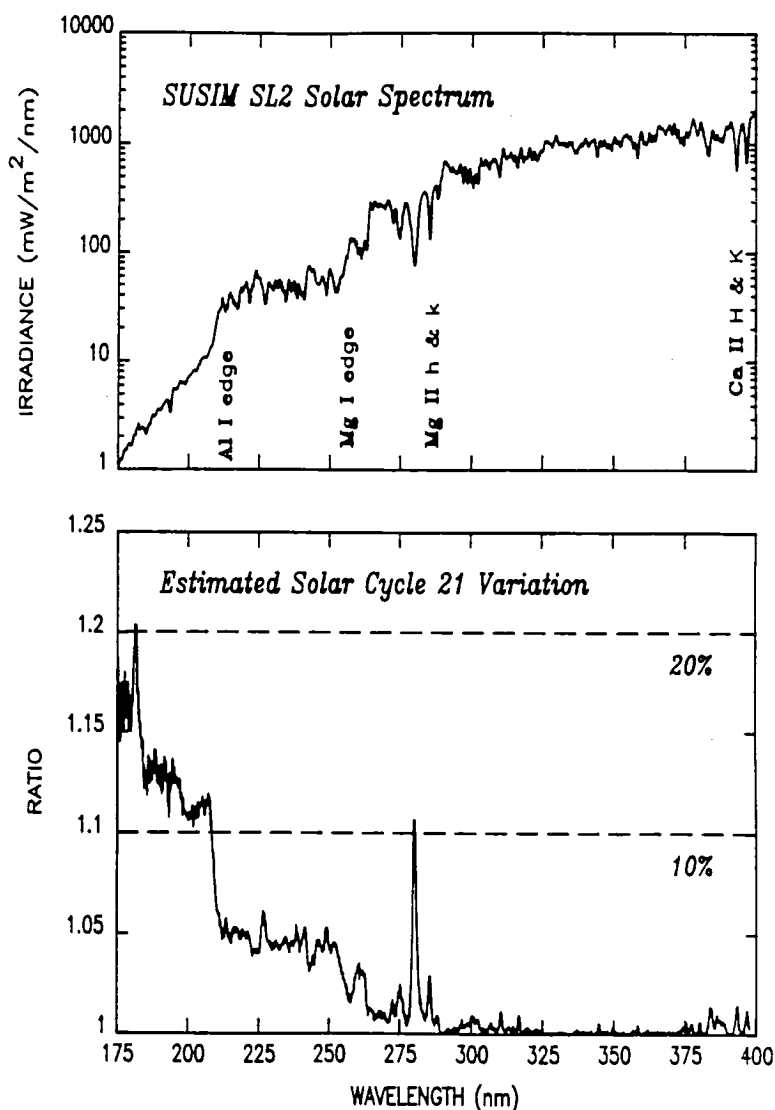
Fig. 1. Solar spectral irradiance, showing the percentage of the total irradiance emitted in specific wavelength intervals.

As illustrated in Figure 1, approximately half of the sun's total irradiance is emitted at wavelengths between 400 and 800 nm, with only ~1% of the irradiance emitted at UV wavelengths less than 300 nm. However, variations in the UV portion of the sun's spectrum, which is formed higher in the sun's atmosphere than is the visible radiation, significantly exceed those at visible wavelengths. Estimates of UV irradiance variations during solar cycle 21 are shown in Figure 2. Like the total irradiance, the UV irradiances have their maximum values at times near maximum solar activity. However, the magnitude of the UV irradiance variations are more than an order of magnitude larger than the ~0.08% variation in the total solar irradiance that has been observed during solar cycle 21.[1]
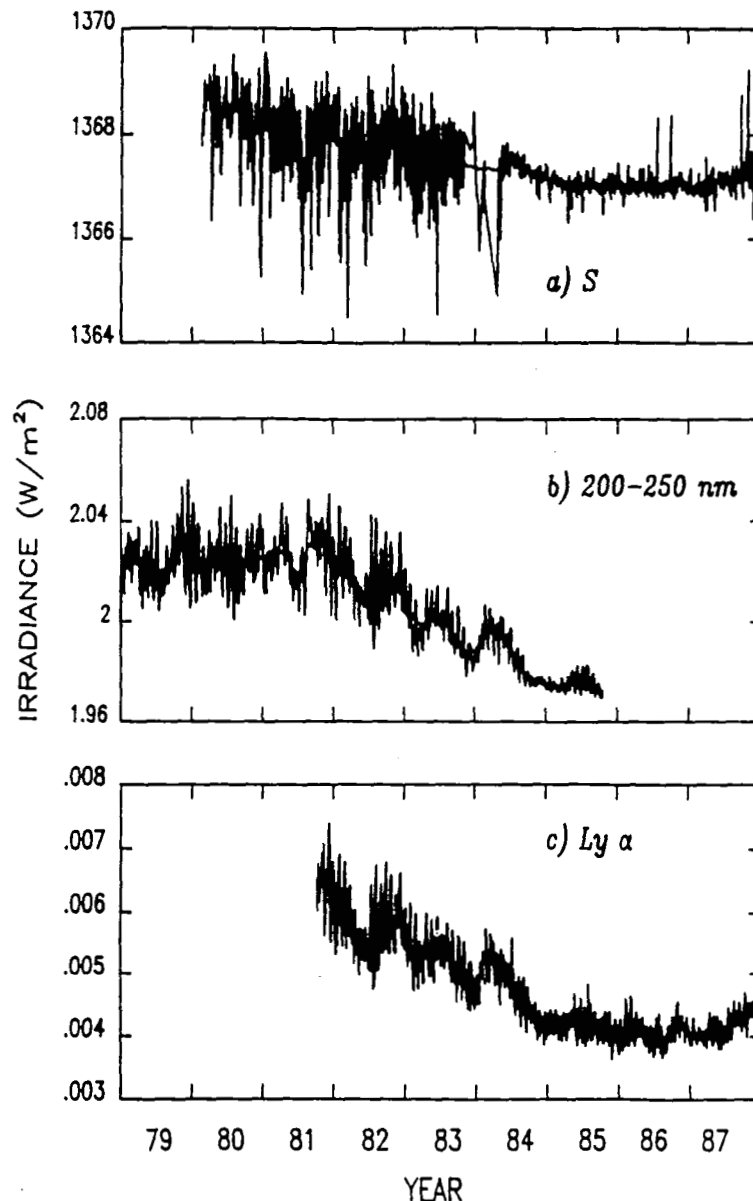
Simultaneous observations during solar cycle 21 of the sun's total irradiance, S, and of the UV spectral irradiances at 205 nm and at 121.57 nm (HI Lα) are illustrated in Figure 3. It has been shown recently, using data similar to that in Figure 3, that changes in the sun's energy at wavelengths from 200 to 300 nm, although only 1% of the total radiative output, accounted for 19% of the decrease in total irradiance from July 1981 to June 1985[1]. This is because at UV wavelengths the emission deficit in sunspots is negligible compared with enhanced emission from faculae, whereas at wavelengths between 400 and 800 nm, where faculae contrast is much less than at UV wavelengths, the sunspot deficit and faculae enhancements are of the same order and therefore exert compensatory effects on the total irradiance.

Fig. 2. Solar UV spectral irradiances measured by the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)[2] on SpaceLab-2 (upper panel), and an estimate of UV irradiance variability during solar cycle 21 (lower panel).
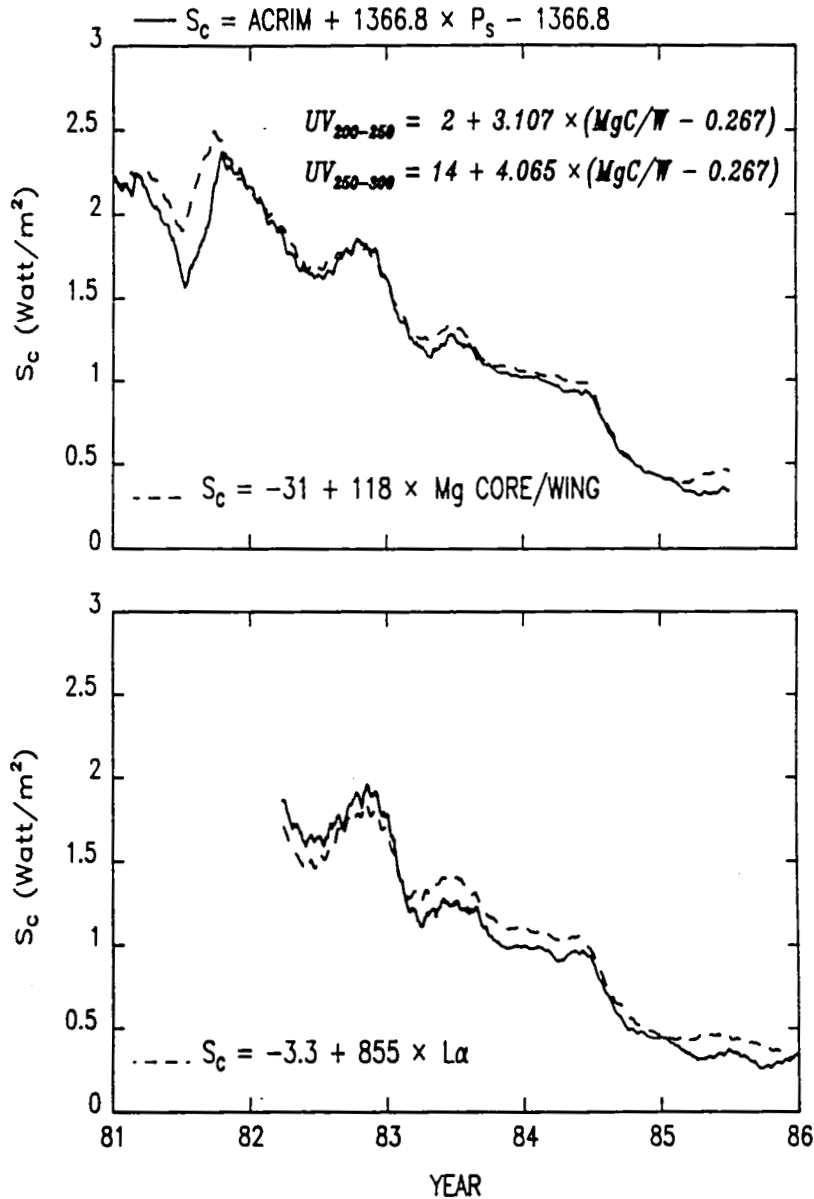
Since the solar UV irradiances have been shown, during solar cycle 21, to contribute significantly more to variations in the total irradiance than the 1% they contribute to the total irradiance itself, it is of interest to determine how changes in solar UV emissions have modulated total irradiance variations on historical time scales. This is investigated using an empirical model of the sun's total irradiance variations that accounts separately for the contribution of dark sunspots and bright faculae.[3] In this model, which is described in detail elsewhere in these proceedings,[4] the sunspot blocking is determined directly from observations of the areas and locations of sunspots on the solar disc. Enhanced emission from bright faculae is estimated from a facular proxy via its correlation with a residual irradiance time series, $S-P_s-S_o$, calculated by subtracting the sunspot blocking from the measured total irradiances during times when both the proxy data and measurements of S are available. To estimate bolometric facular emission during solar cycles prior to cycle 19,[3,4] monthly mean $R_z$ are used as the facular proxy.



Fig. 3. Variations during solar cycle 21 and the beginning of solar cycle 22 in a) the total solar irradiance, S, measured by the Active Cavity Radiometer (ACRIM)[5] on the Solar Maximum Mission satellite, b) the UV irradiance from 200 to 250 nm, determined from the Mg Index empirical model[6] and c) the HI Lα irradiance at 121.57 nm, measured by the Solar Mesosphere Explorer (SME).[7]

In order to partition the total facular brightness at all wavelengths into its UV and non-UV portions, it is necessary to establish the relationship between the two. Figure 4 illustrates that temporal variations in the measured irradiance residuals, $S-P_S-S_O$, are closely tracked by variations in the independently determined UV irradiances. This has been demonstrated elsewhere, over both solar rotation and solar cycle time scales,[1,3,4] and is consistent with an understanding of the origin of the brightness source of total irradiance variations as being magnetic flux tubes; these carriers of solar activity extend from the photosphere, where the visible radiation is formed, to the top of the chromosphere, from where L$\alpha$ is emitted.
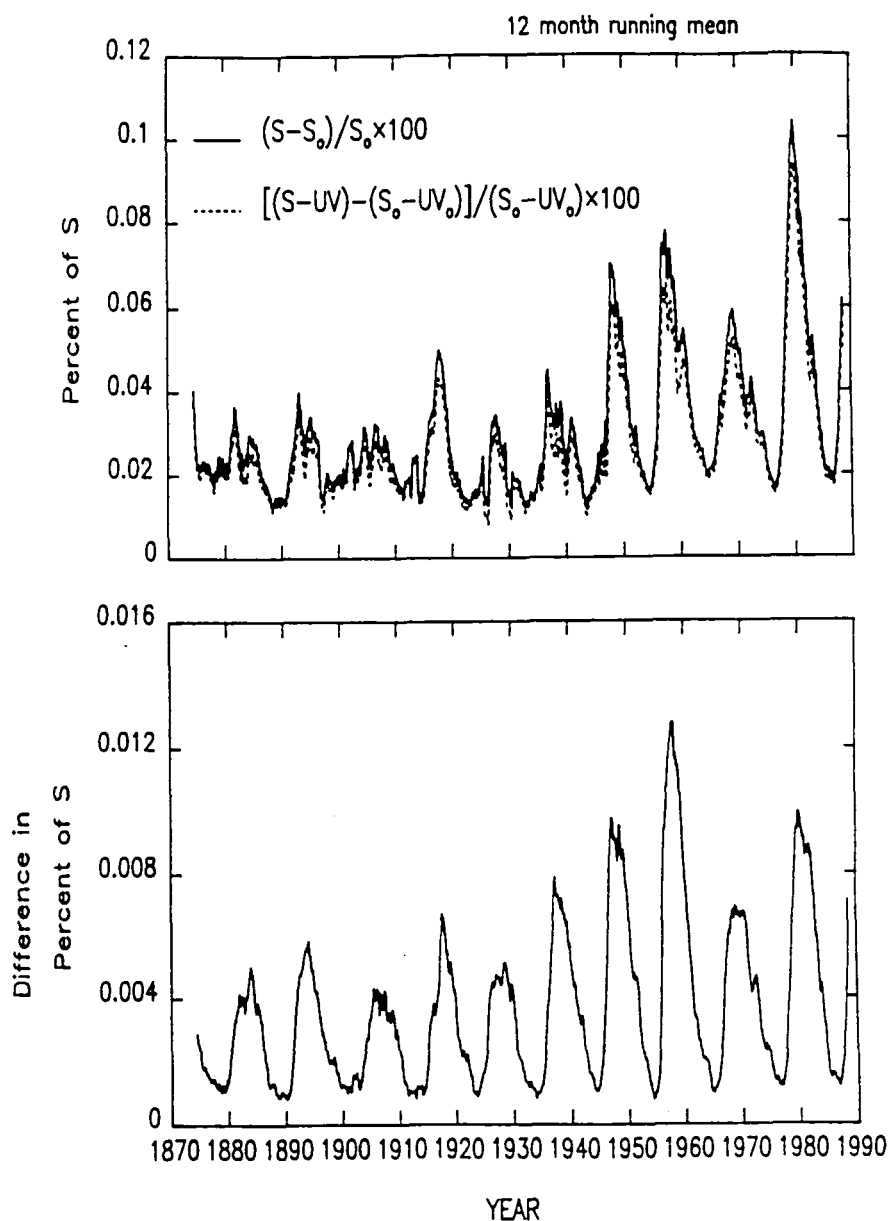


Fig. 4. Irradiance residuals, $S-P_S-S_O$, derived from the total irradiance, S, measured by ACRIM, compared with a reconstruction of the residuals from the Mg Index (upper panel) and the L$\alpha$ irradiance (lower panel).

## ESTIMATED TOTAL IRRADIANCE VARIATIONS EXCLUDING ULTRAVIOLET IRRADIANCE VARIATIONS

Because changes in the sun's UV emission are related, approximately linearly, to variations in the total irradiance facular emission, the UV portion of the enhanced facular brightness can be easily subtracted from the bolometric facular emission. The facular term, reduced by its UV component, $S-P_S-S_O-UV$, is then combined with $P_S$ to estimate variations in the sun's total irradiance, at wavelengths longward of 300 nm. These variations are compared in Figure 5 with variations in the sun's total irradiance, determined from the same empirical model, but with the UV component of the facular emission retained. Figure 5 suggests that during solar cycles 12 to 21, according to these calculations, the variation in the sun's total irradiance incident on the earth's surface was reduced, by as much as 20%, from that at the top of the earth's atmosphere.

When the various solar activity time series, such as $R_z$, $F_{10.7}$ and the UV irradiances are studied closely, differences in their detailed temporal structures are evident. Because of this, the model calculation shown in Figure 5 must be considered as indicative only of the UV-related component in the actual solar irradiance variations. Nevertheless, the results in Figure 5 suggest that in each cycle of solar activity since cycle 12, the UV emissions have contributed to the variability of the sun's total irradiance disproportionately to their fraction of the irradiance itself, and in such a way as to increase the amplitude in its 11-year cycle.



Fig. 5. Percent changes in S, with and without the UV irradiance at 200 to 300 nm (upper panel), and the difference between them (lower panel).

## FUTURE MEASUREMENTS OF TOTAL AND UV SOLAR IRRADIANCES

Understanding the role played by the sun's UV emission variations in the broader context of total irradiance variability will be improved when simultaneous observations of both the UV and total irradiances are made during solar cycle 22. The reliability of future UV irradiance observations should exceed those made in solar cycle 21 which were hampered by wavelength dependent changes in instrument responsivity. It is planned, during solar cycle 22, to launch together on the Upper Atmosphere Research Satellite (UARS) three solar irradiance monitors, the Active Cavity Radiometer (ACRIM II), the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) and the Solar Stellar Irradiance Comparison Experiment (SOLSTICE). Figure 6 is a schematic of SUSIM. With multiple optical elements, the radiometric redundancy designed into the SUSIM experiment will allow detailed on-board monitoring of instrument responsivity. Data collected by these instruments will significantly improve our understanding of the magnitude and temporal variability of the sun's total irradiance, its UV spectral irradiance, and the interconnection between them.
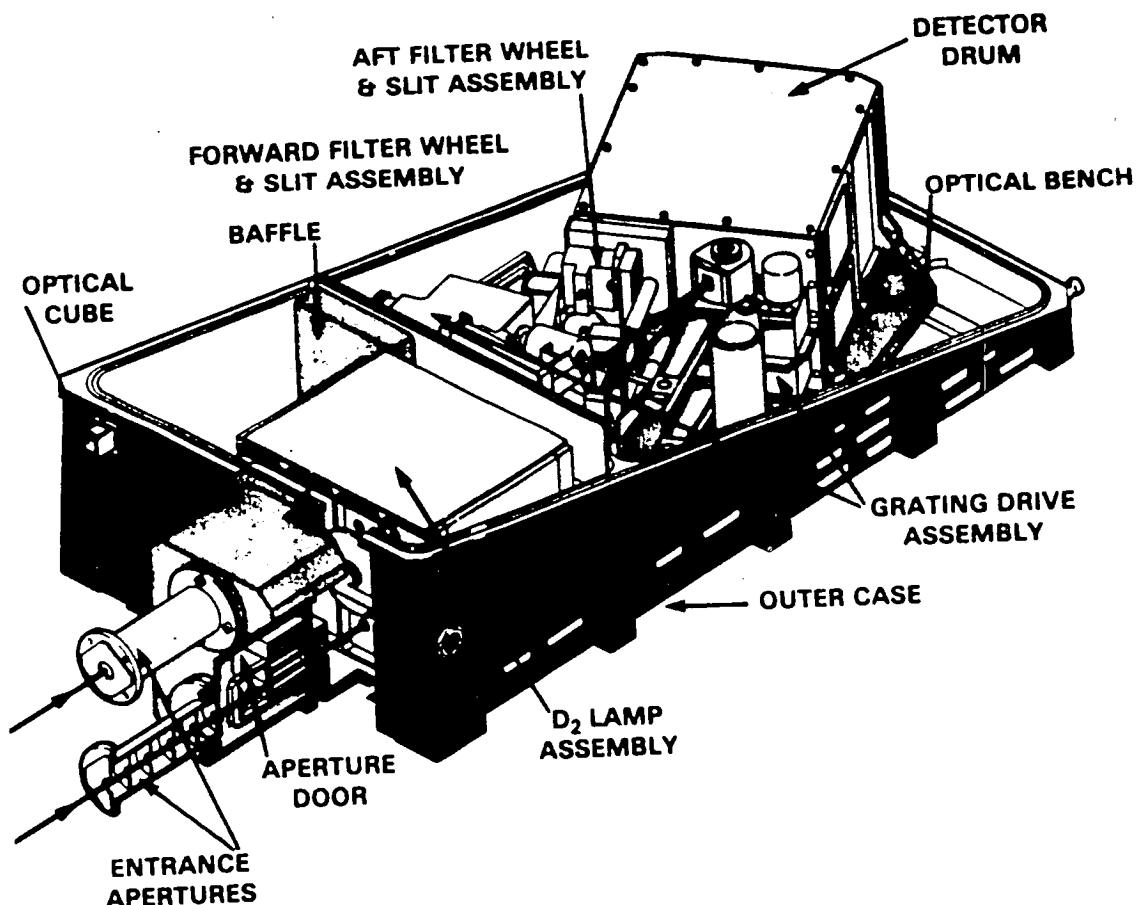
Fig. 6. NRL's SUSIM instrument, to be launched on the UARS satellite in mid 1991.

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